Incorporating beneficial electrification in distribution planning

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Training Webinars on Electricity System Planning
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Grid Modernization Laboratory Consortium.

Outline

- Beneficial Electrification
  - Definition

Training Focus:

- Transportation Electrification and Distribution System Planning
  - Challenges
  - Solutions
- Building Electrification and Distribution System Planning
  - Challenges
  - Solutions

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Beneficial Electrification - Definition

Beneficial electrification can be described as the use of electricity to power devices where doing so satisfies at least one of the following conditions without adversely affecting any of the others [1]:

- It saves consumers money over time.
- It benefits the environment and reduces greenhouse gas emissions.
- It improves product quality or consumer quality of life.
- It fosters a more robust and resilient electrical grid.

[1] https://www.cooperative.com/topics/beneficial-electrification/Documents/Beneficial-Electrifcation-Fact-Sheet.pdf

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Transportation Electrification

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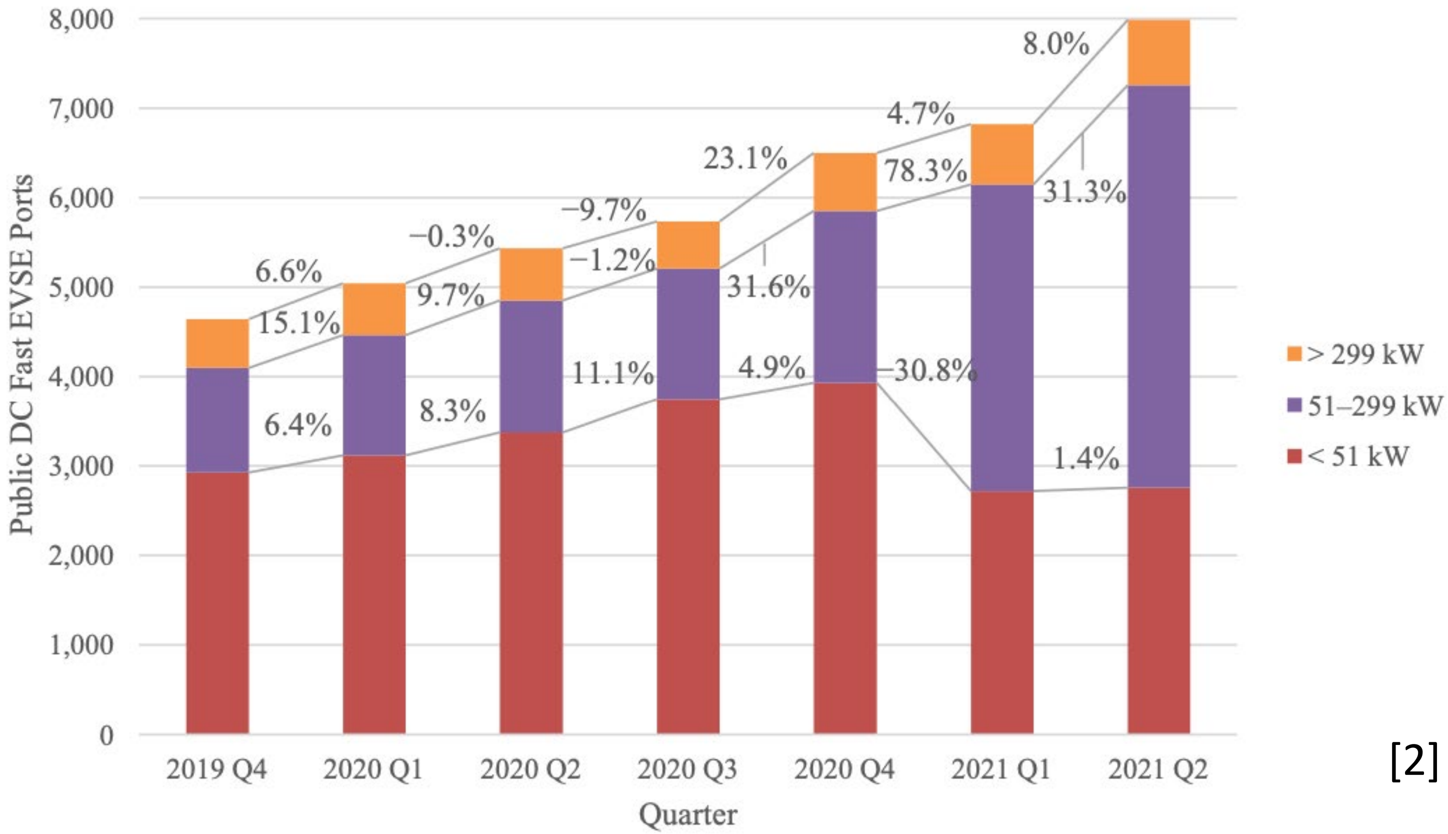
Energy Information Administration (EIA) project electric vehicles (EVs)—any LDV with a charging plug—will grow from 0.7% of the global LDV fleet in 2020 to 31% in 2050 [1]

The Biden Administration has established a goal of building a national public charging network of 500,000 electric vehicle supply equipment (EVSE) ports by 2030. To meet this goal by 2030, approximately 14,706 public EVSE port installations will be required each quarter for the next 9 years — a significant increase from the 5,322 public EVSE ports that have been installed each quarter on average since the start of 2020. [2]

[1] https://www.eia.gov/todayinenergy/detail.php?id=50096

[2] Brown, Abby, Johanna Levene, Alexis Schayowitz, and Emily Klotz. *Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: Second Quarter 2021*. No. NREL/TP-5400-81153. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2021.

Quarterly growth of public DC fast EVSE ports by power output



[2]

[2] Brown, Abby, Johanna Levene, Alexis Schayowitz, and Emily Klotz. *Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: Second Quarter 2021*. No. NREL/TP-5400-81153. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2021.

Challenges to the Grid

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- How to evaluate the grid impact
- What grid impacts to expect
- How to plan charging stations in a way which can minimize the impact
- What solutions can be deployed to mitigate the adverse impact

Solutions Addressing the Challenges

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- ► Voltage Impact Matrix (VIM) based grid impact evaluation
- ► Monte-Carlo based charging load modeling
- ► Charging station planning considering transportation factors
- ► Onsite renewable energy generation (e.g., solar and energy storage)

✓ Developed for medium/heavy duty EV, can be used for both light duty EV and medium/heavy duty EV

VIM-Base Grid Impact Evaluation

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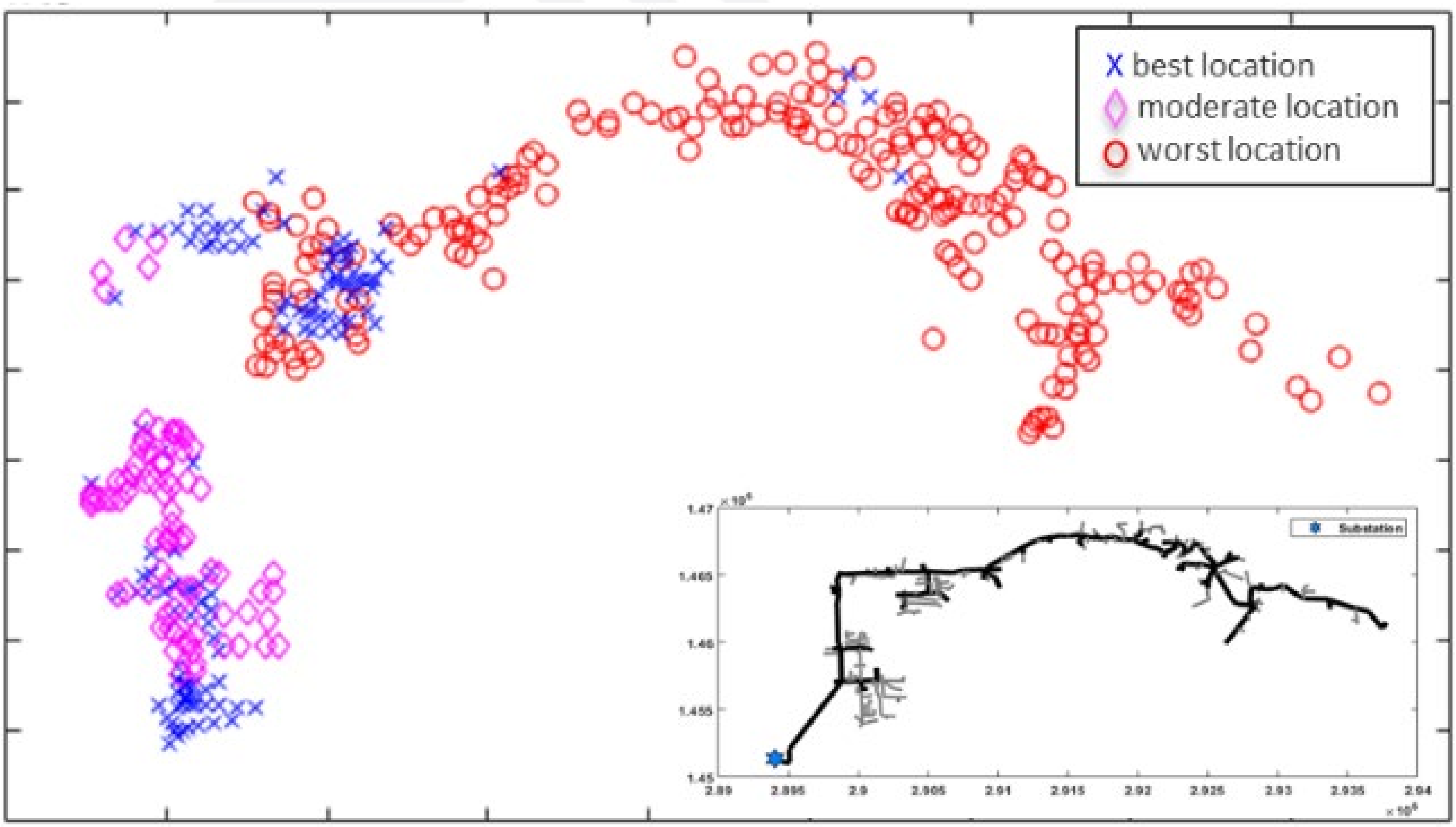
Larger value → Worse location

Smaller value → Better location

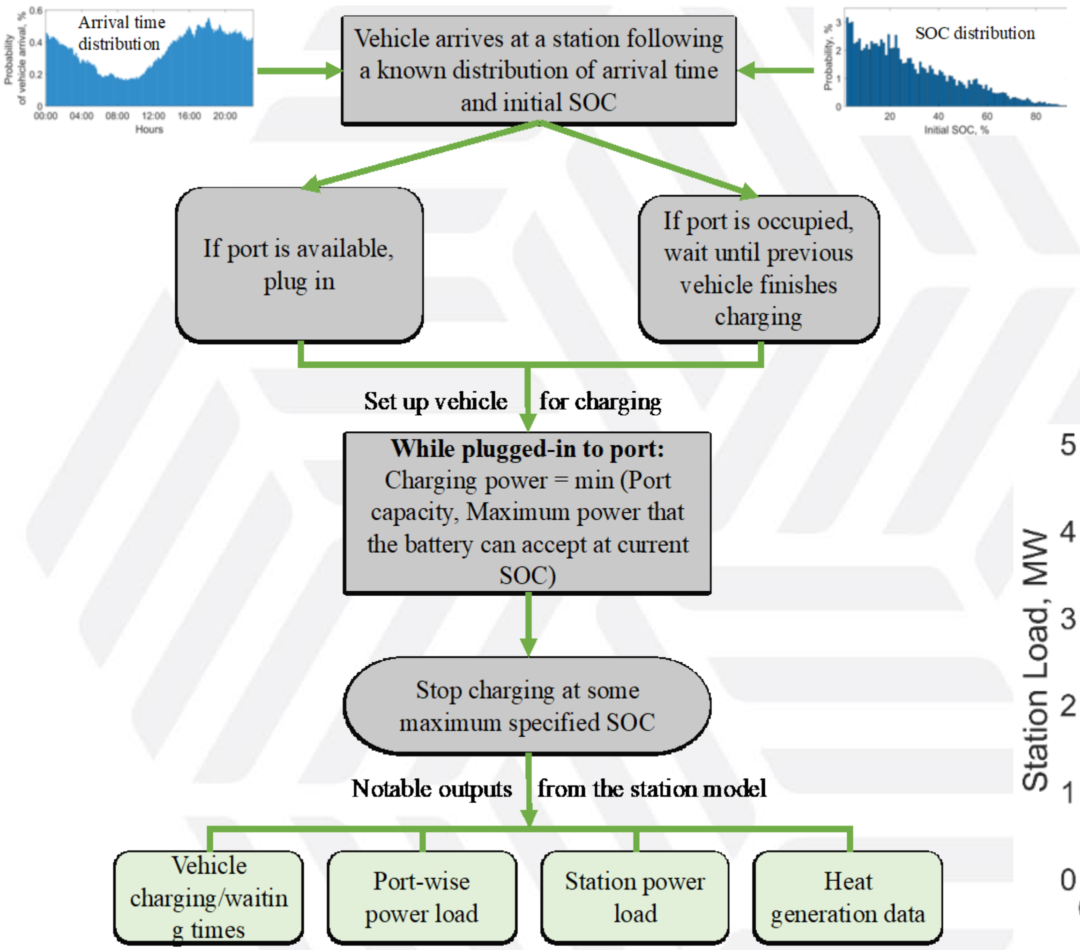
- Voltage Impact Matrix (VIM) represents the voltage impact of a node on the system. VIM is developed based on Voltage Load Sensitivity Matrix (VLSM).
- VLSM [4] is used to evaluate and quantify the voltage impact of each connection point in the system.

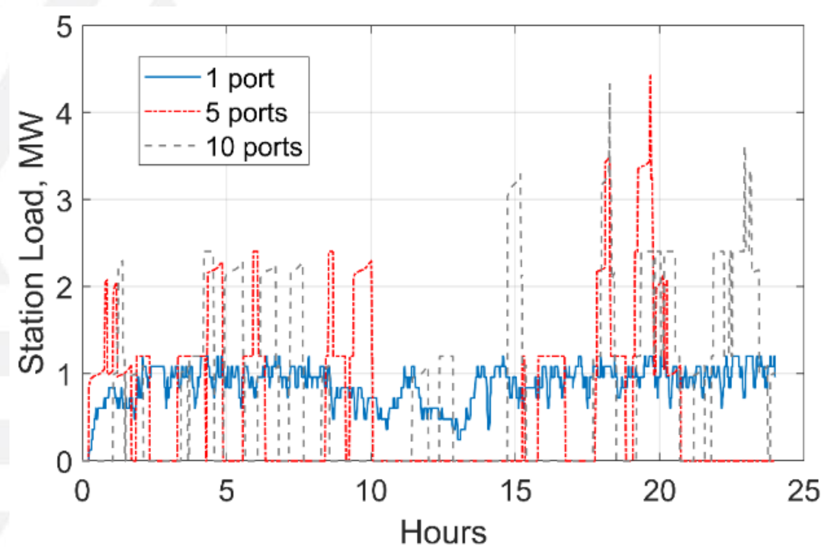
[4] Zhu, Xiangqi, Jiyu Wang, Ning Lu, Nader Samaan, Renke Huang, and Xinda Ke. "A hierarchical vlsm-based demand response strategy for coordinative voltage control between transmission and distribution systems." *IEEE Transactions on Smart Grid* 10, no. 5 (2018): 4838-4847.

Grid Impact-Based Charging Station Location Evaluation



Monte-Carlo Based Charging Load Modeling: Medium And Heavy Duty EV

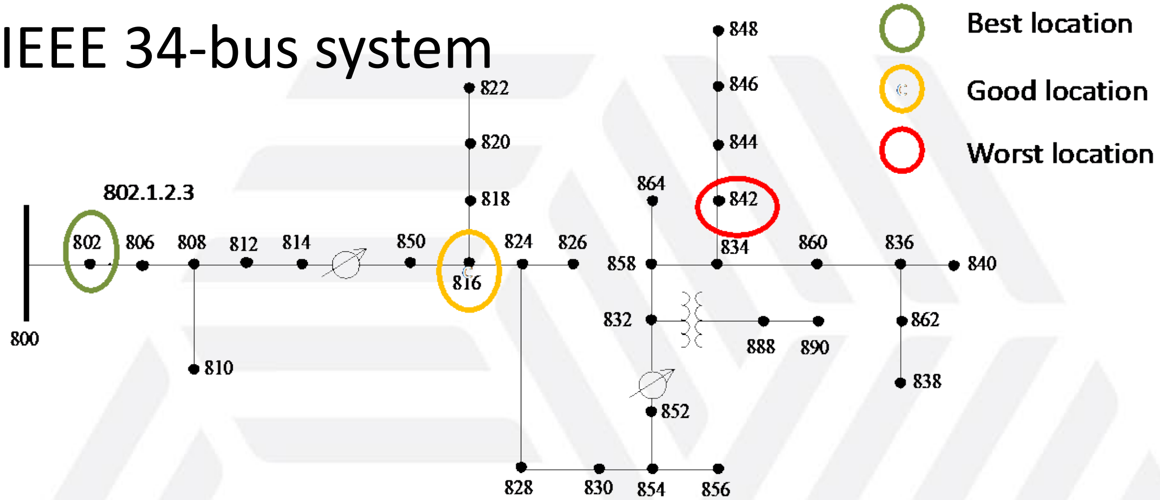




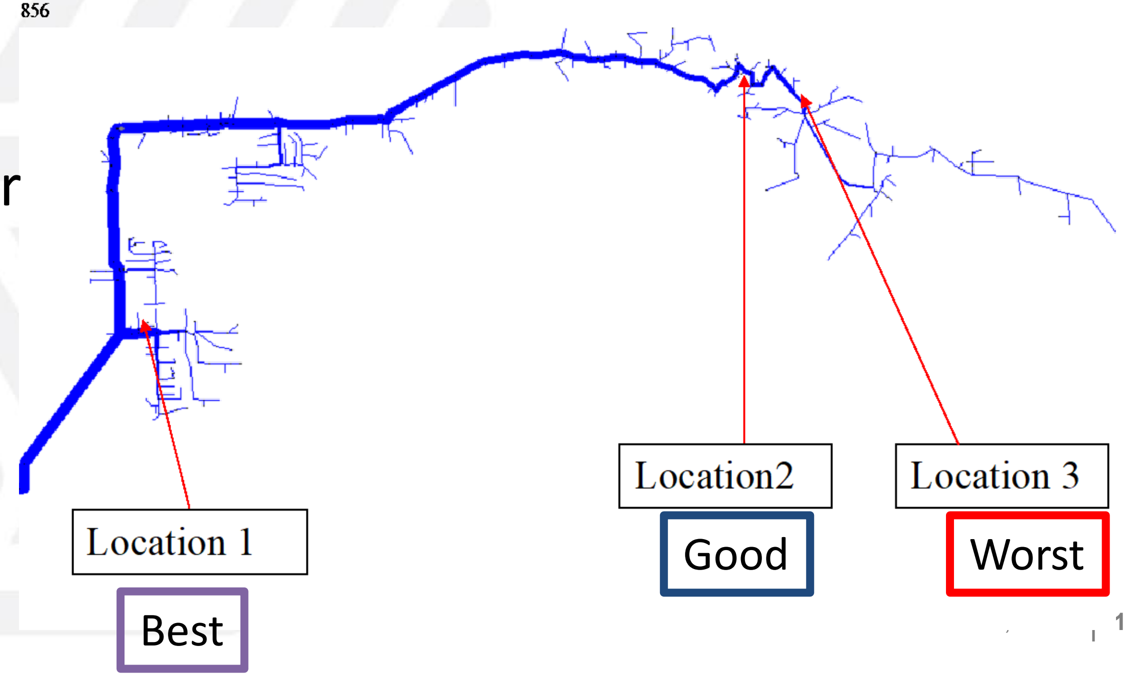
[5] Zhu, Xiangqi, Barry Mather, and Partha Mishra. "Grid impact analysis of heavy-duty electric vehicle charging stations." In *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, pp. 1-5. IEEE, 2020.

Case Studies

IEEE 34-bus system

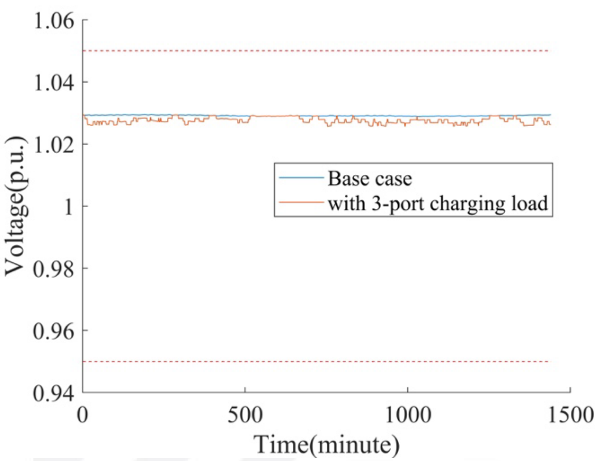


Realistic feeder

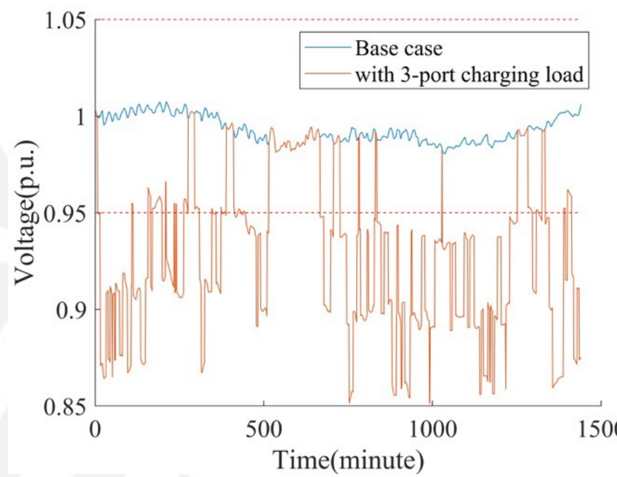


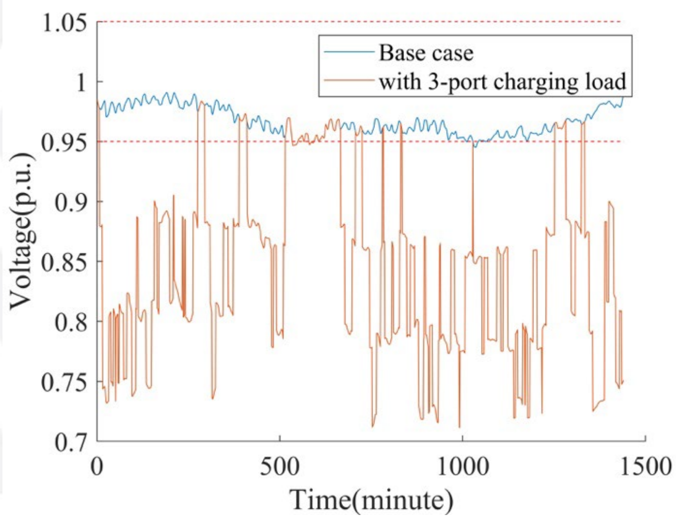
Voltage Impact – IEEE 34-bus Feeder

Case 1 - Best location



Case 2 - Good location





Case 3 - Worst location

Voltage Impact – IEEE 34-bus Feeder

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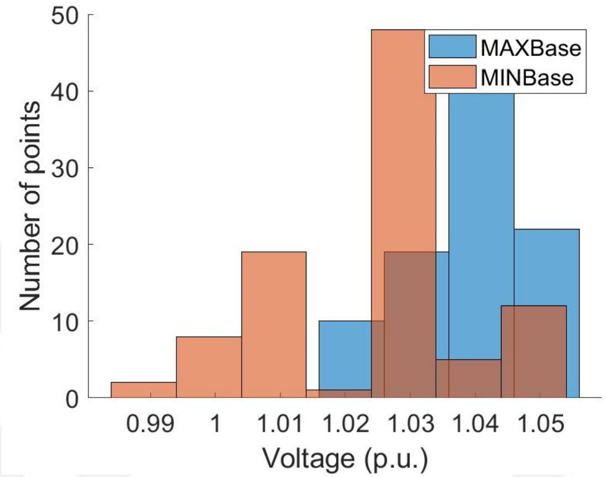
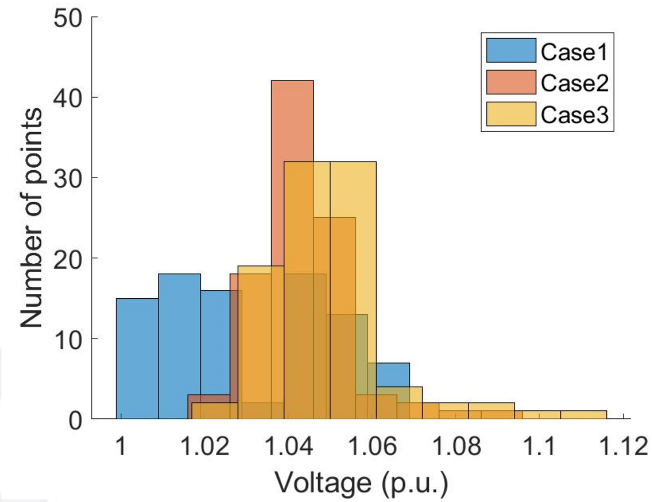
Base case

A



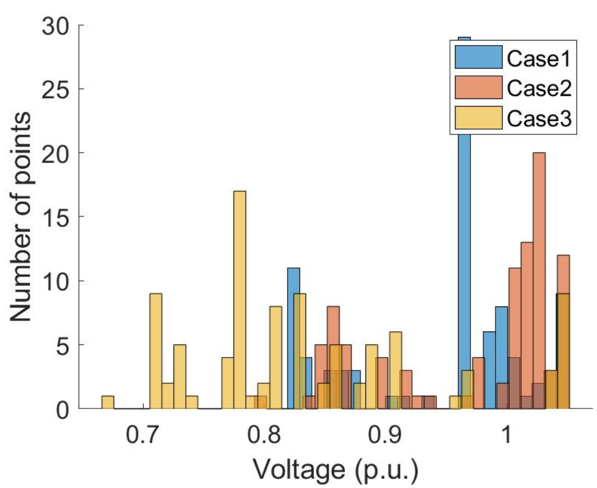
Maximum voltage distribution

B



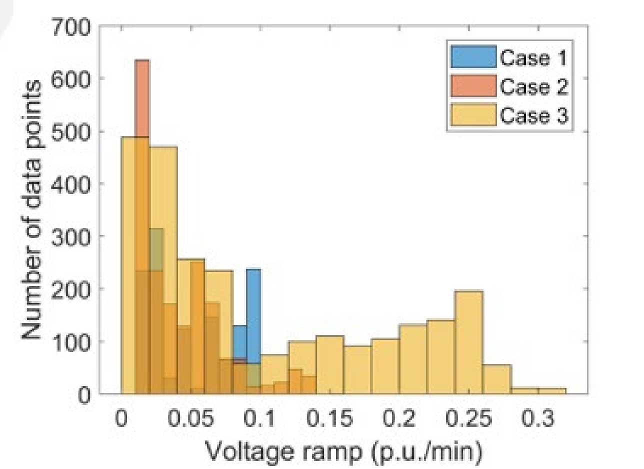
Minimum voltage distribution

C



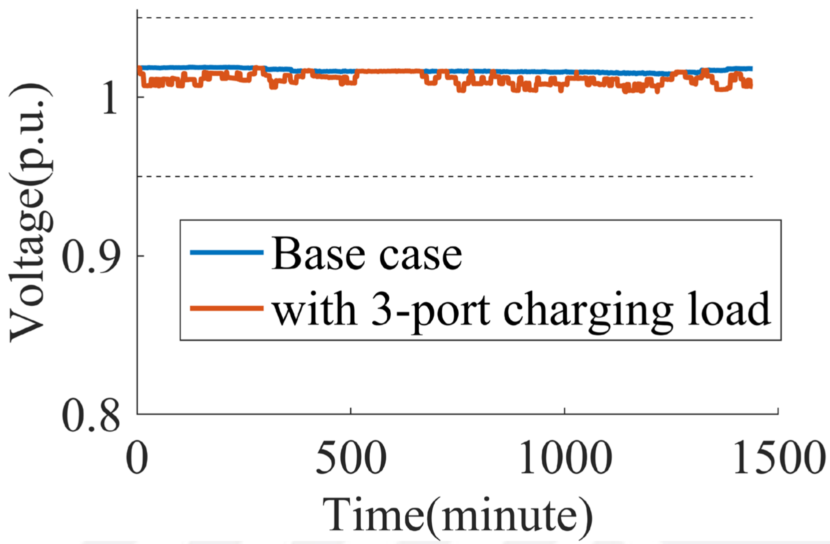
Voltage ramp distribution

D

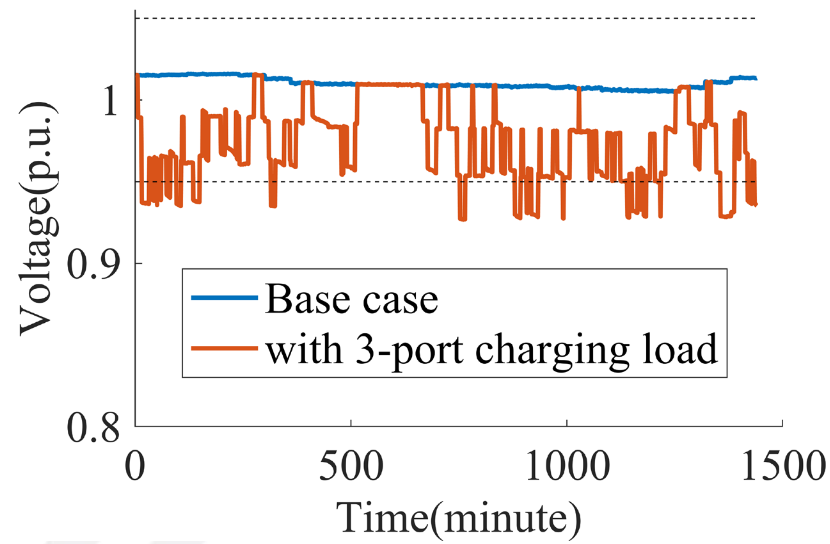


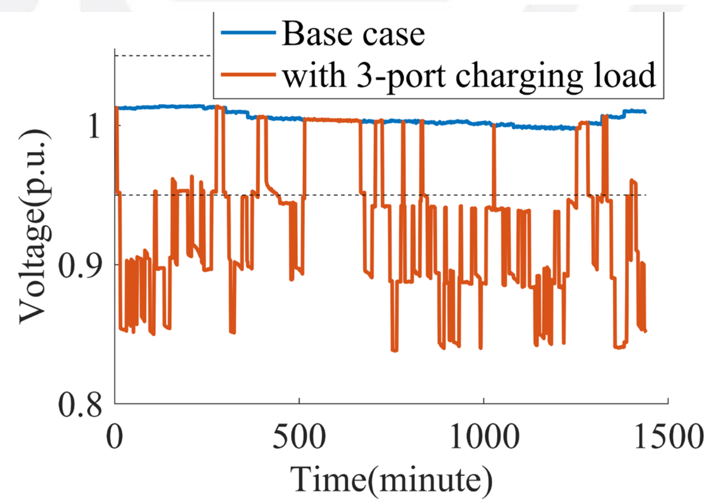
Voltage Impact – Realistic Single Feeder

Best location



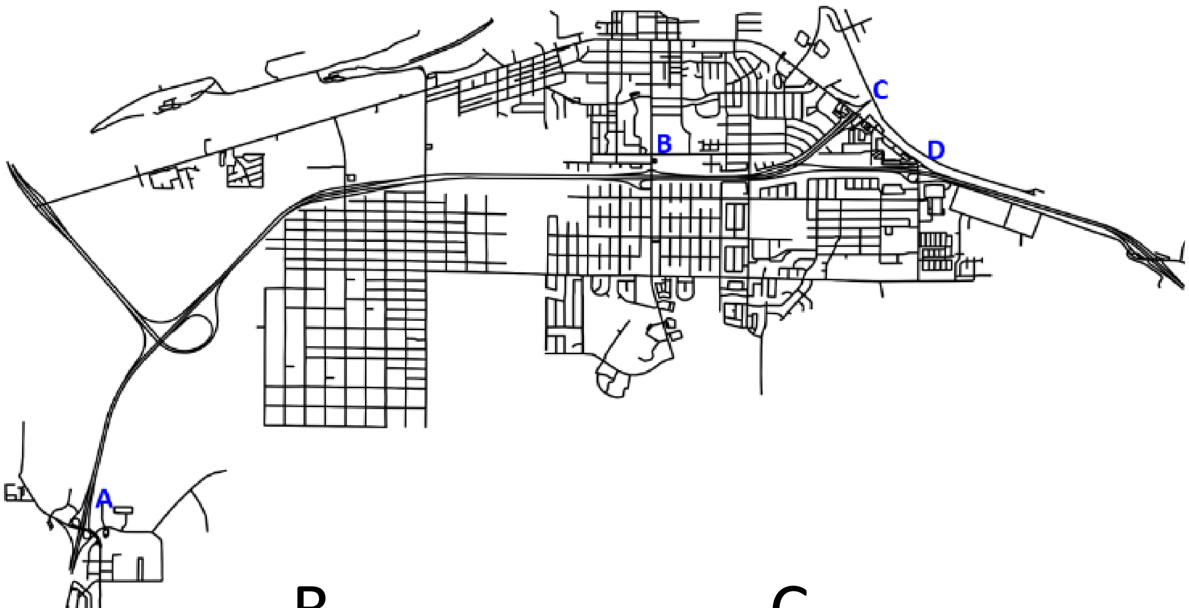
Good location





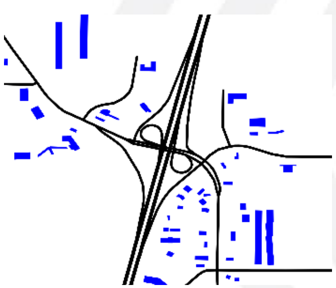
Worst location

Transportation Factor Considered Charging Station Planning



- OpenStreet Map
- Supporting facilities
- Grid impact
- Transportation considerations

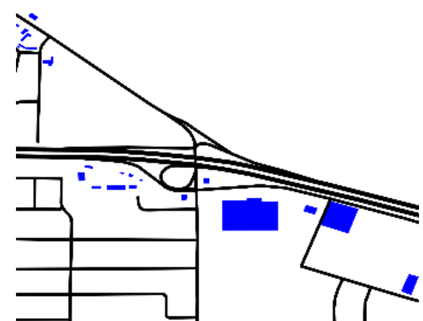
A



B

C

D



[6] Zhang, Mingzhi, Xiangqi Zhu, Barry Mather, Pranav Kulkani, and Andrew Meintz. "Location Selection of Fast-Charging Station for Heavy-Duty EVs Using GIS and Grid Analysis." In *2021 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, pp. 1-5. IEEE, 2021.

Light-Duty EV Grid Impact Example - Minneapolis

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Impact of Residential EV charging

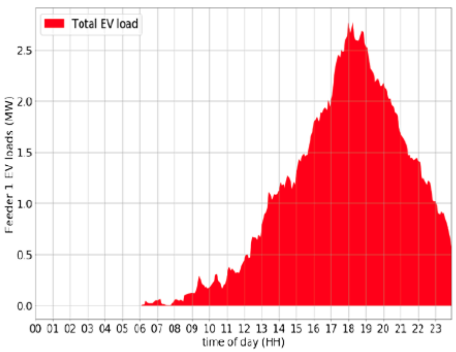
"Reasonable":
2030 High, Home-Dominant

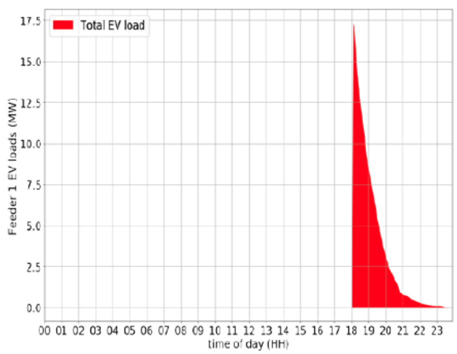
Under "reasonable" EV charging, EV impacts are modest due to medium EV adoption (**20-85% of personal vehicles are EVs**)* and weakly correlated charge start times. Some of the feeders in older parts of the metro exceed or are close to exceeding the thermal limits in this scenario. These feeders represent about 3.1% of EV load in Minneapolis for this scenario.

"Extreme": 1.8 EVs per Residential Customer; All EVs Begin Charging at 6PM

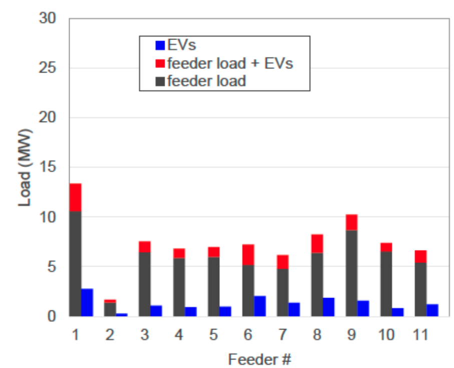
In the "extreme" case, **100% of personal vehicles are EVs**, and charge start times are perfectly correlated. This leads to line overloading and under voltage impacts on all feeders that have a lot of residential customers.

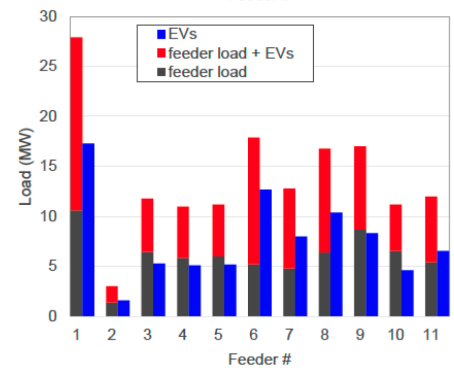
EV Load [MW]



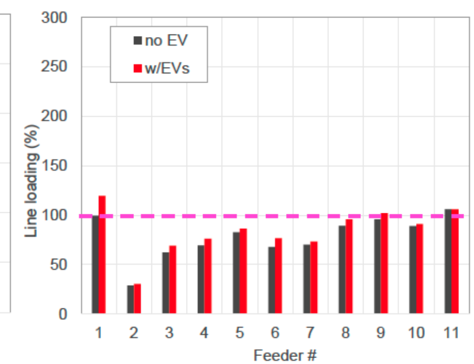


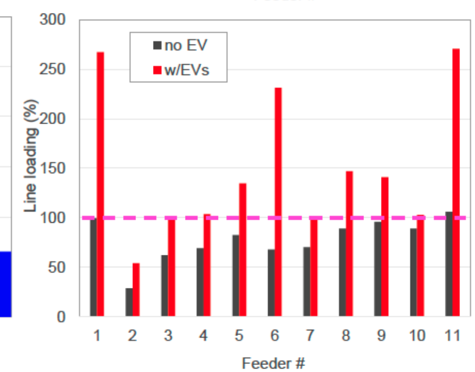
Total Load at Peak [MW]





Line Loading at Peak [%]





* Estimate is based on 1.8 EVs per residential customer on each feeder

NREL | 14

[7] https://www.nrel.gov/docs/fy20osti/76717.pdf

Light-Duty EV Grid Impact Example - Atlanta

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Impact of Residential EV charging

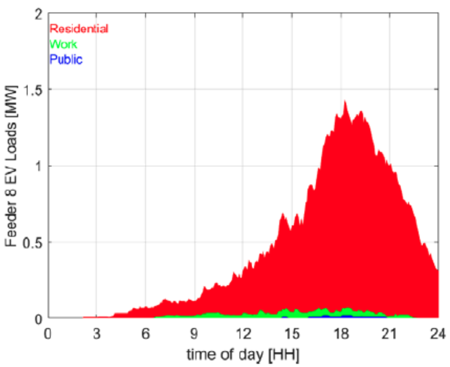
EV Load [MW]

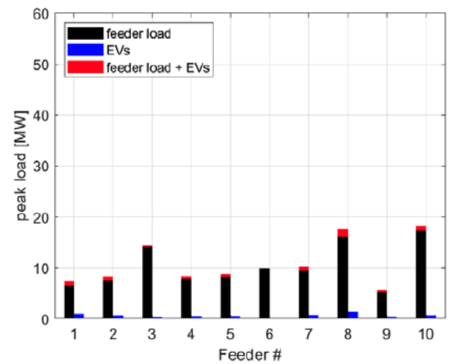
Total Load at Peak [MW]

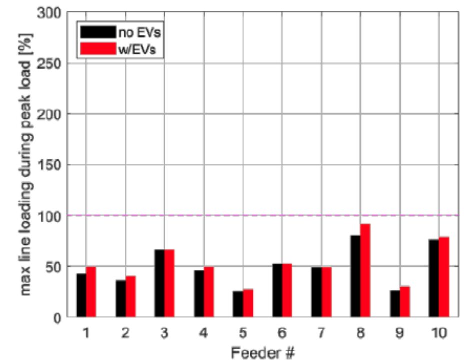
Line Loading at Peak [%]

"Reasonable":
2030 High, Home-Dominant

Under "reasonable" EV charging, EV impacts are modest due to medium EV adoption (**5-60% of personal vehicles are EVs**)* and weakly correlated charge start times. These feeders represent about 1.9% of peak EV load in Atlanta for this scenario.







"Extreme": 1.8 EVs per Residential Customer; All EVs Begin Charging at 6PM

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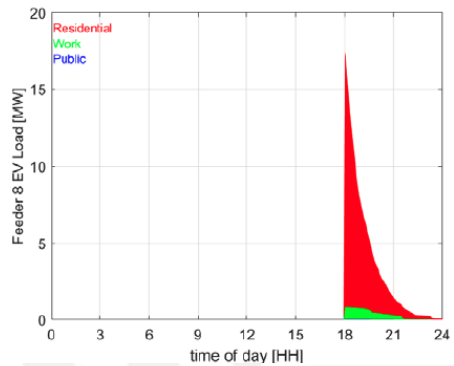
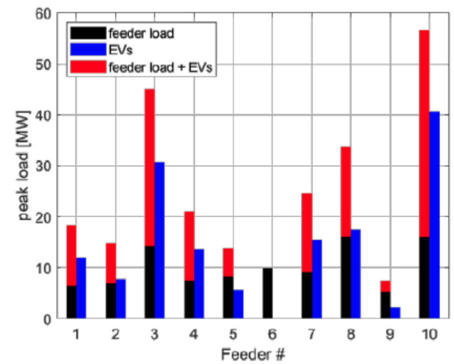
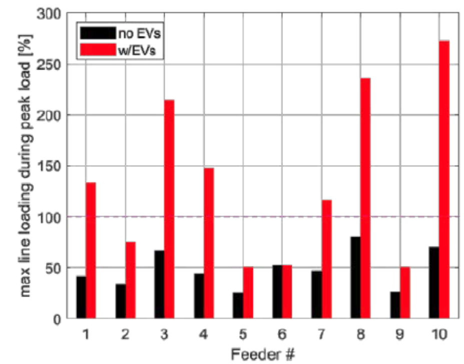
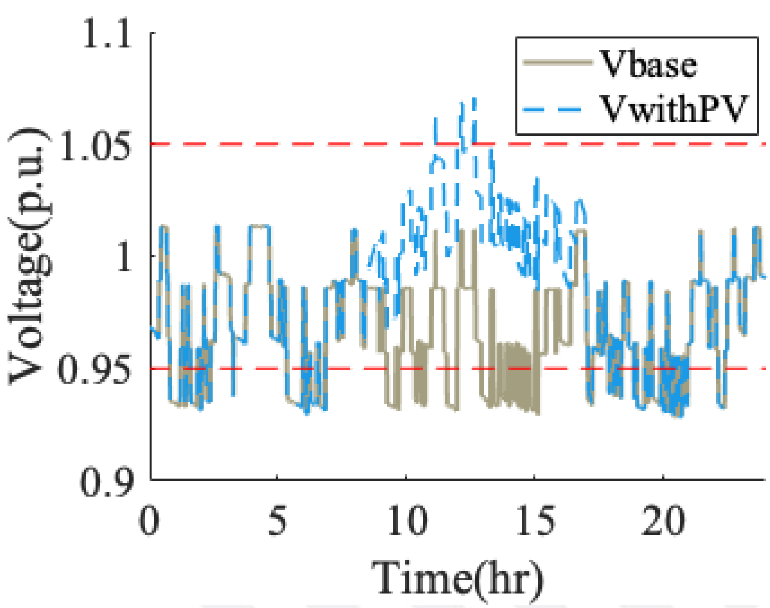




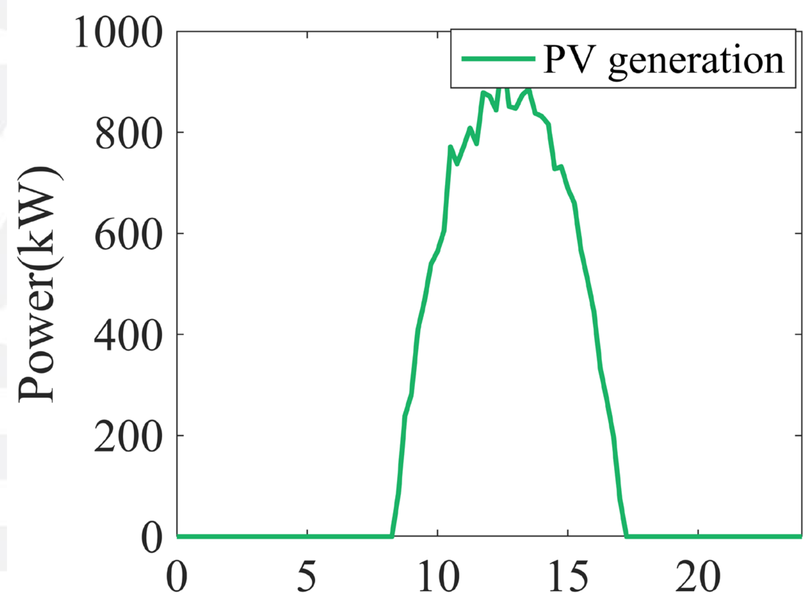


[7] https://www.nrel.gov/docs/fy20osti/76717.pdf

Onsite PV Generation

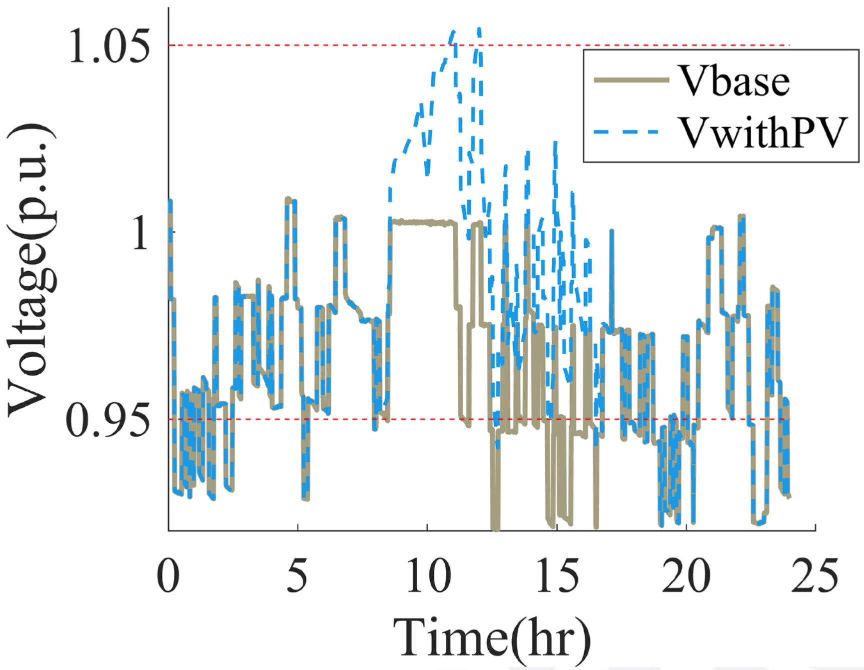


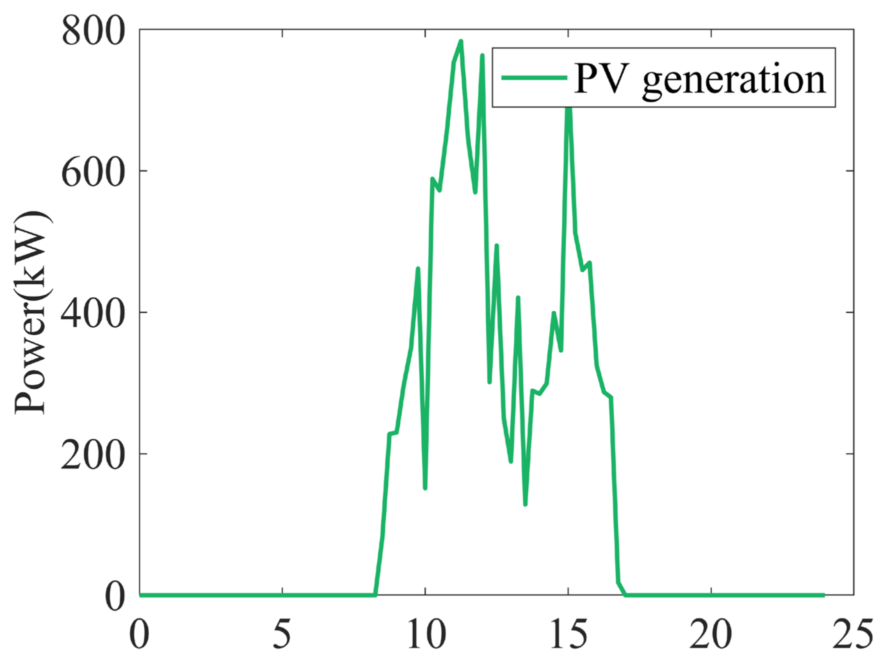
Sunny Day



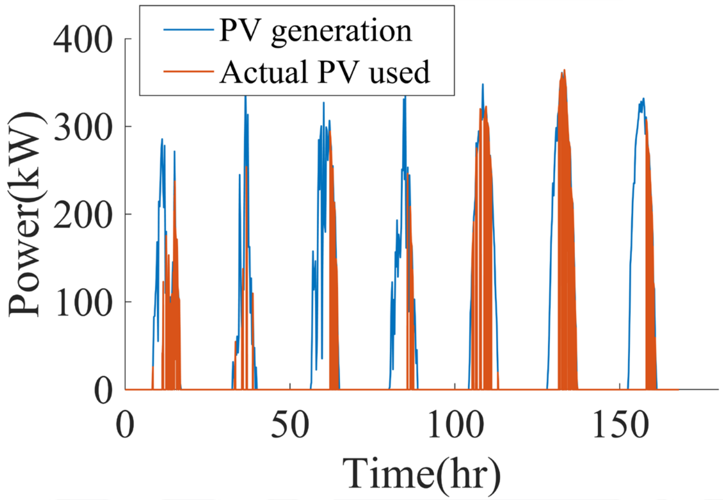
Onsite PV Generation

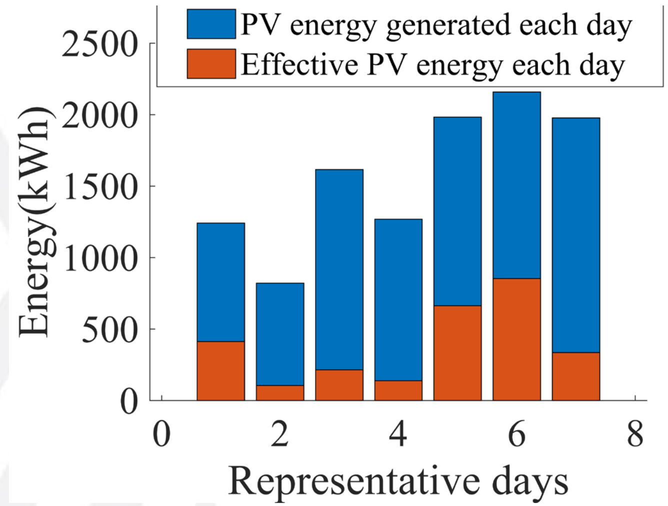
Cloudy Day



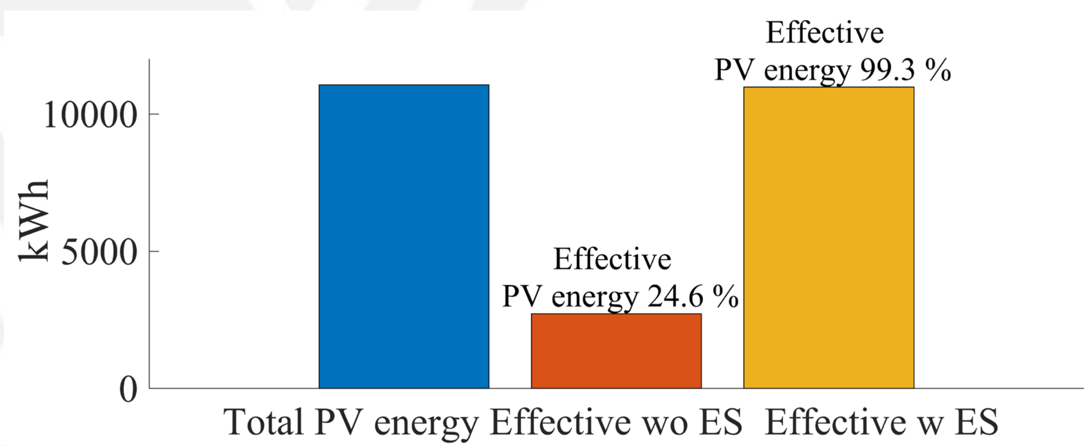


Onsite PV and Energy Storage



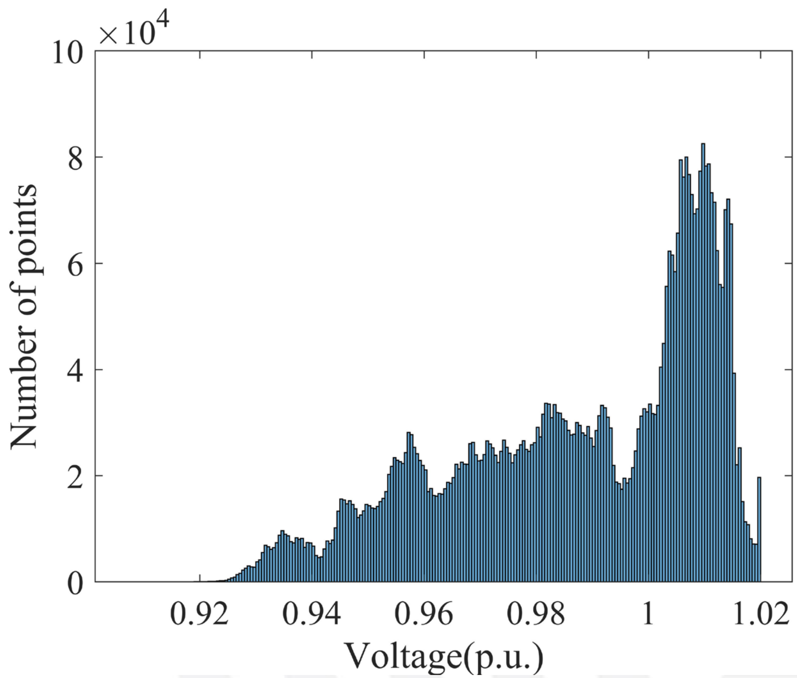


With energy storage (1641 kWh/364 kW)

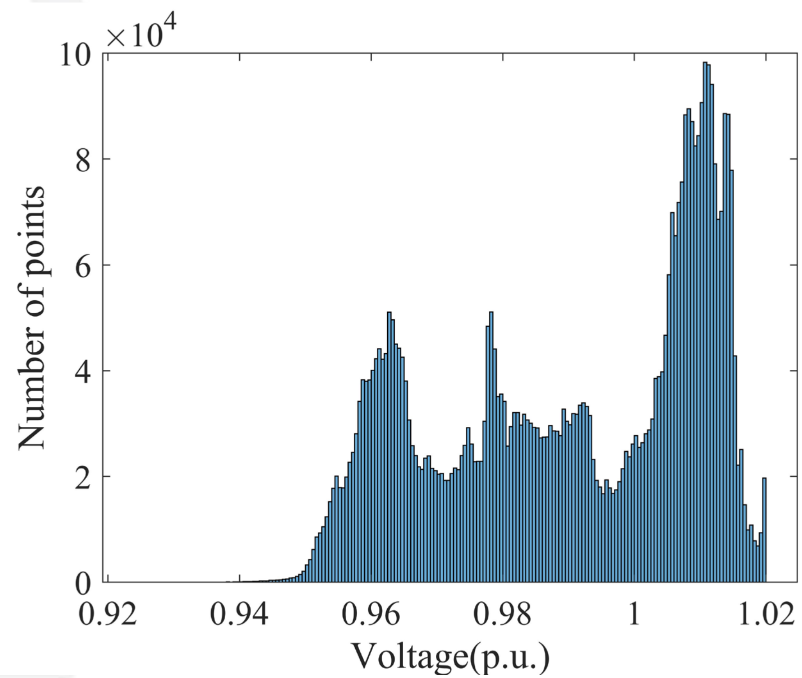


Impact Mitigation Performance – PV, ES, and Smart Charger

Voltage distribution before mitigation

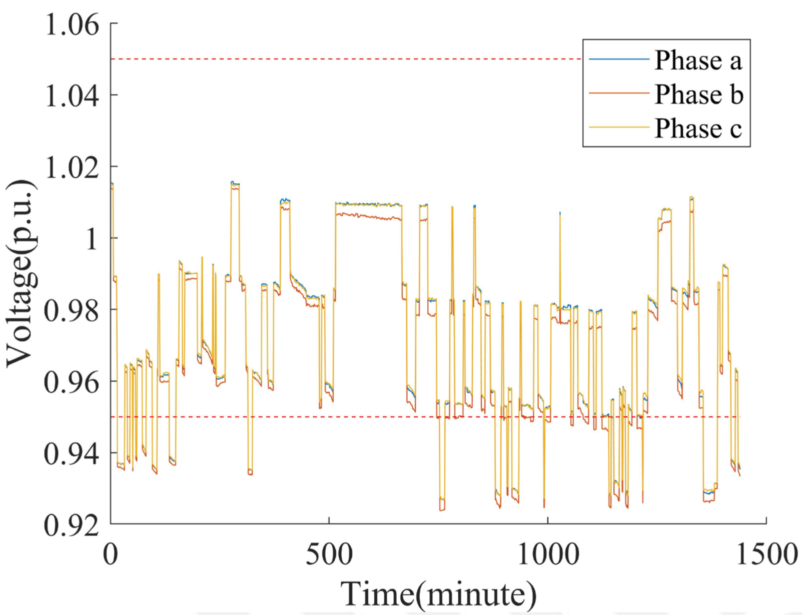


Voltage distribution after mitigation

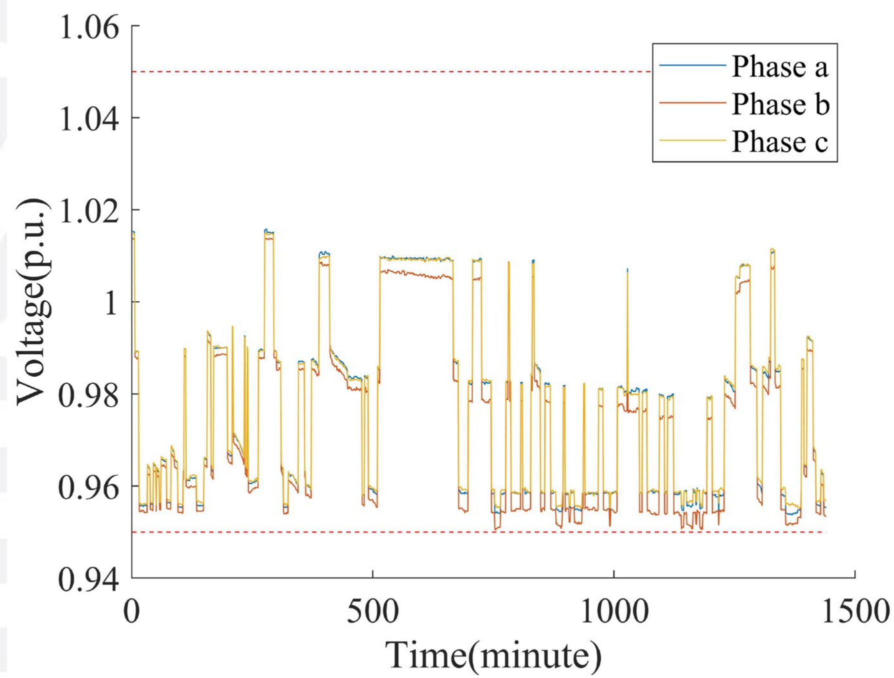


Impact Mitigation Performance – PV, ES, and Smart Charger

One-day voltage profile before mitigation



One-day voltage profile after mitigation



PV, Energy Storage, and Smart Charger Size Selection

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To balance the sizes of each part of the PV-ES-charger on-site solution, we propose a methodology to achieve the optimal size combinations of the PV, ES, and smart charger, with the objectives of maintaining the system voltage within limits and minimizing the total capital cost of the on-site PV-ES-charger solution [8].

Scenario Number	Condition	Description
1	$\lambda_{charger} \gg \lambda_{PV-ES}$	C always increases as $S_{charger}$ increases
2	$\lambda_{charger} > \lambda_{PV-ES}$	C always reduces when $S_{charger} < S_{charger}^{set}$ C always increases when $S_{charger} > S_{charger}^{set}$
3	$\lambda_{charger} = \lambda_{PV-ES}$	C always reduces as $S_{charger}$ increases
4	$\lambda_{charger} < \lambda_{PV-ES}$	C always reduces as $S_{charger}$ increases
5	$\lambda_{charger} \ll \lambda_{PV-ES}$	C always reduces as $S_{charger}$ increases

[8] Xiangqi Zhu, Partha Mishra, Barry Mather, Mingzhi Zhang, and Andrew Meintz, “Grid Impact Analysis and Mitigation of En-Route Charging Stations for Heavy-Duty Electric Vehicles”

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Challenges to the Grid

- ► How to understand and host the increasing building loads
  - How to model the load for better analysis and planning

- ► How to manage and take advantage of the building loads
  - How to understand and estimate the load flexibility

Challenges to the Grid

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Distribution System Load Modeling

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► Existing software with load modeling functions:

- Advanced distribution management systems (ADMS) (e.g., GE and Siemens) and distribution system simulators (e.g., Synergi and CYME)

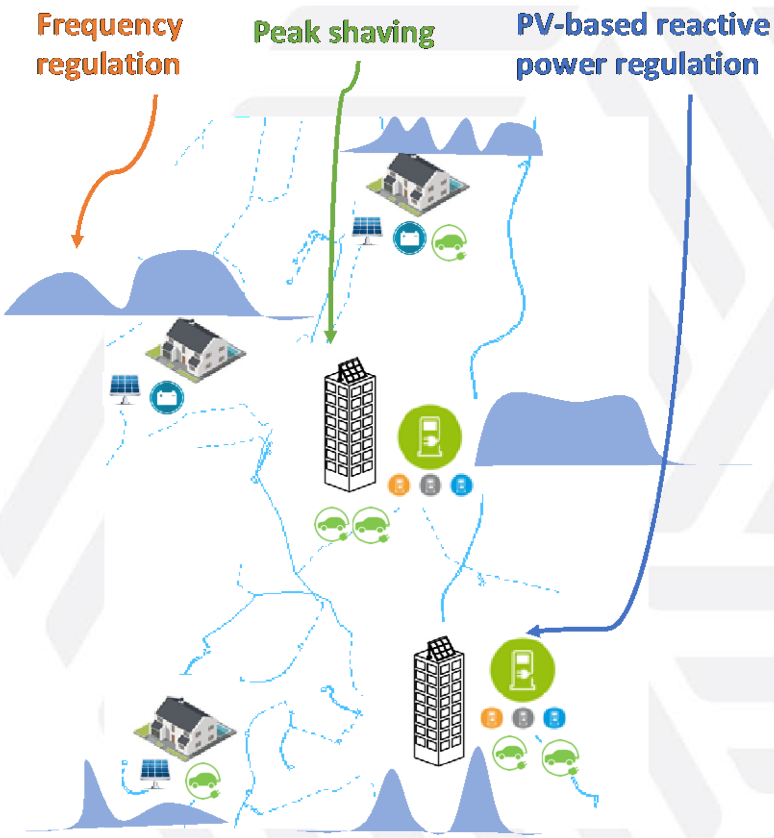
► Current modeling method:

- Standard load allocation – same scaled load shape for all nodes

► New modeling challenges for addressing increased DER penetration:

- Load modeling need to capture load diversity on distribution systems

Advanced Load Scenario and Analysis Tool (ALSAT)



FERC Order 2222 → *DERs participate grid service*

We need

- *Select appropriate customers/providers*
- *Issue correct service signals to buildings/aggregators*

DER-Load interactions are very diverse

Different loads are good for different grid services

Competitors → *Same load shape for all the nodes* →

- *Improper candidate grouping*
- *Wrong signals*

ALSAT → *Diversified load profiles for all nodes* →

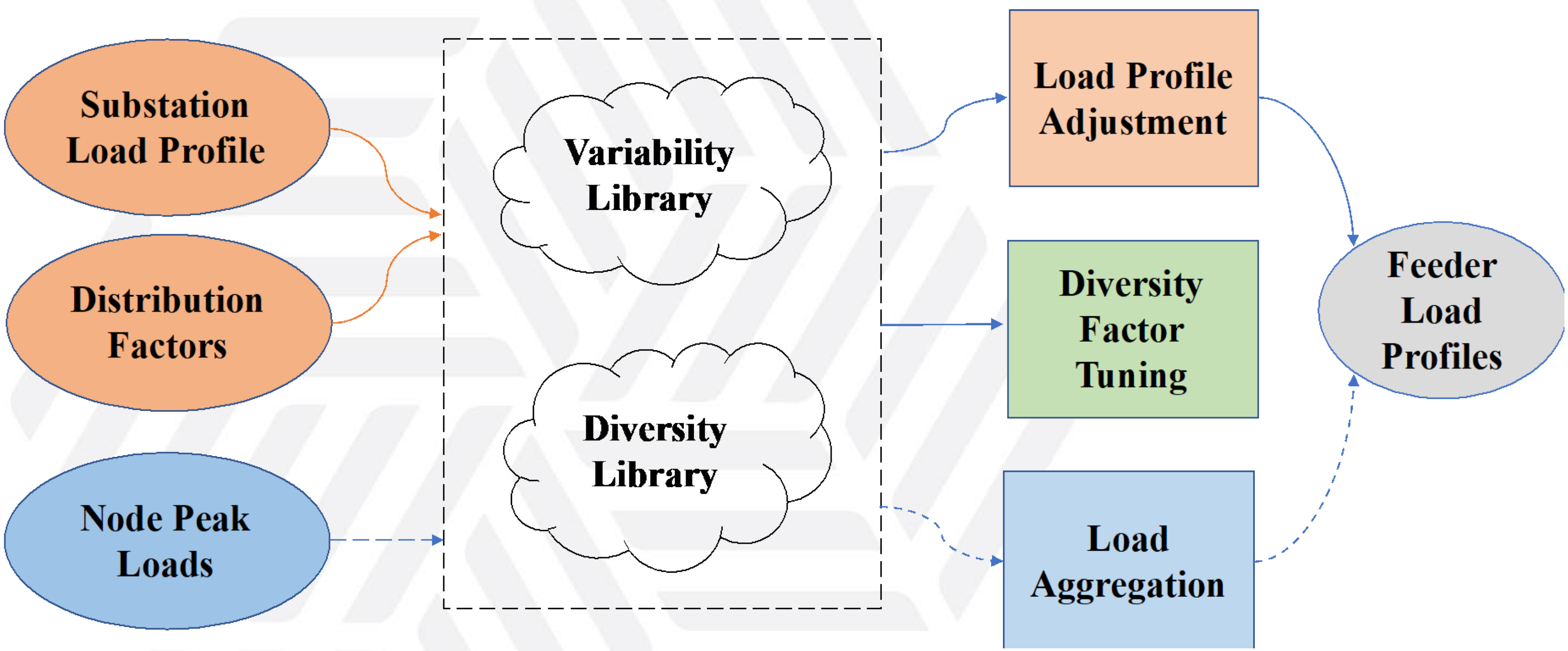
- *More accurate planning, operations, and grid services*

Huge market opportunities and space

https://www.nrel.gov/grid/alsat.html

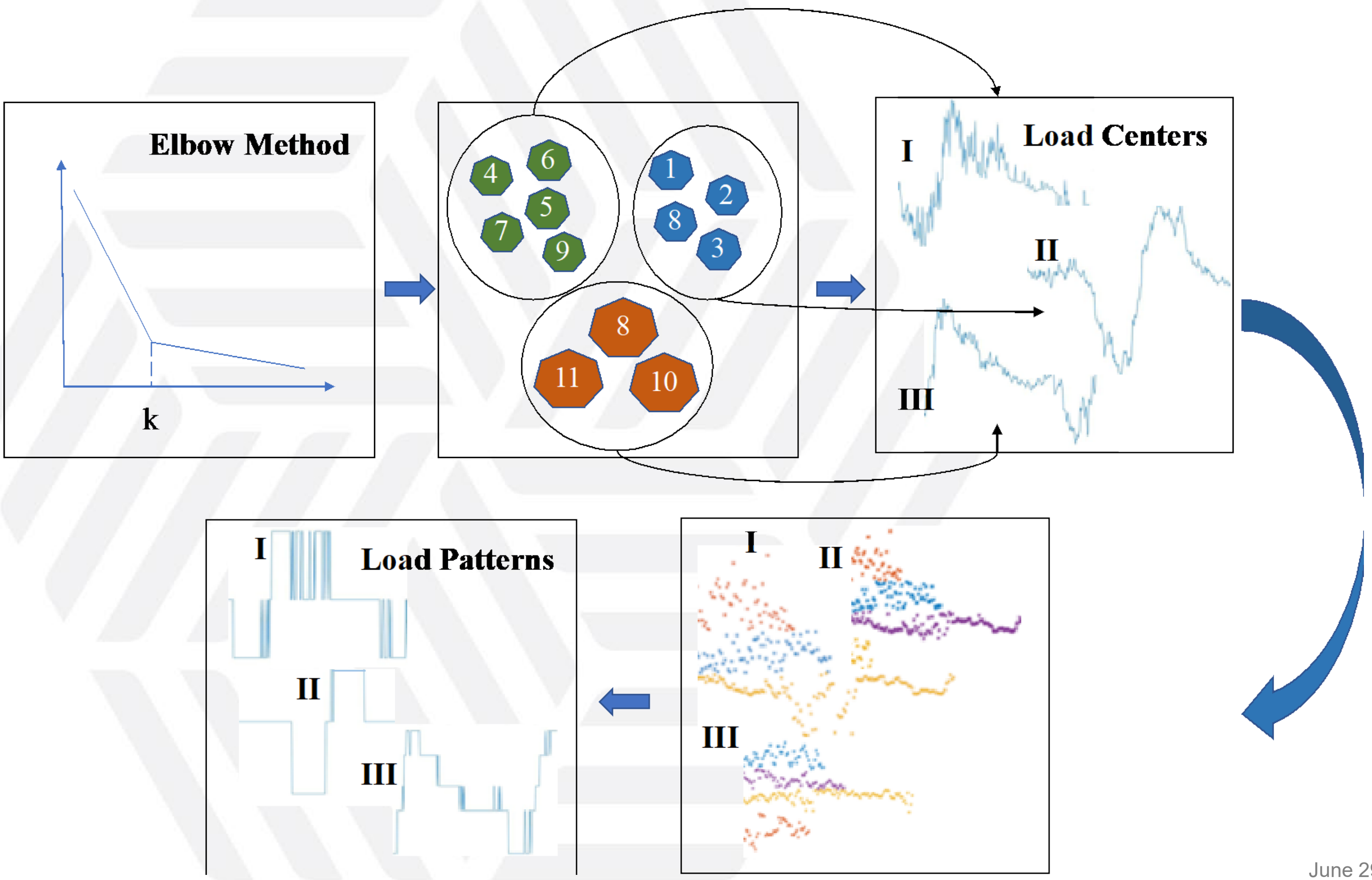
Available for public access soon

Distribution System Load Profile Modeling



Diversity Library - Load Measurements Clustering

K-means is used to cluster the profiles.



Diversity Library - Sample Clusters

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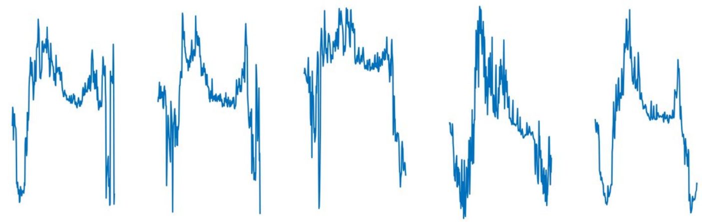
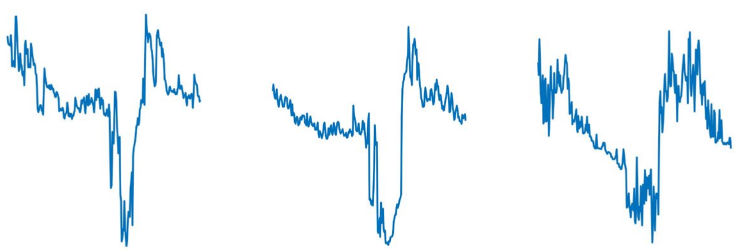
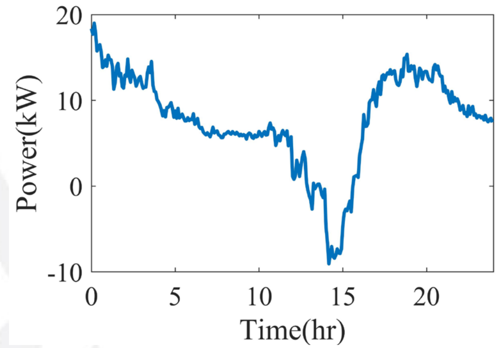
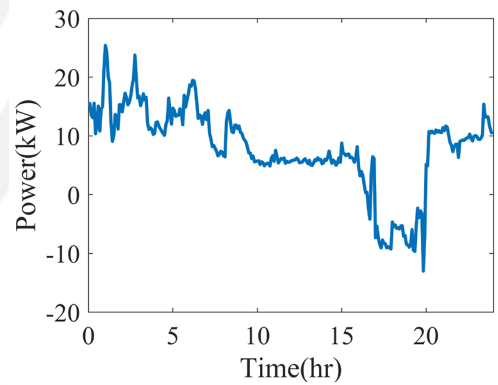
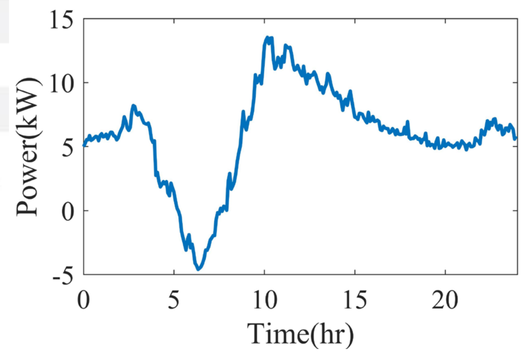




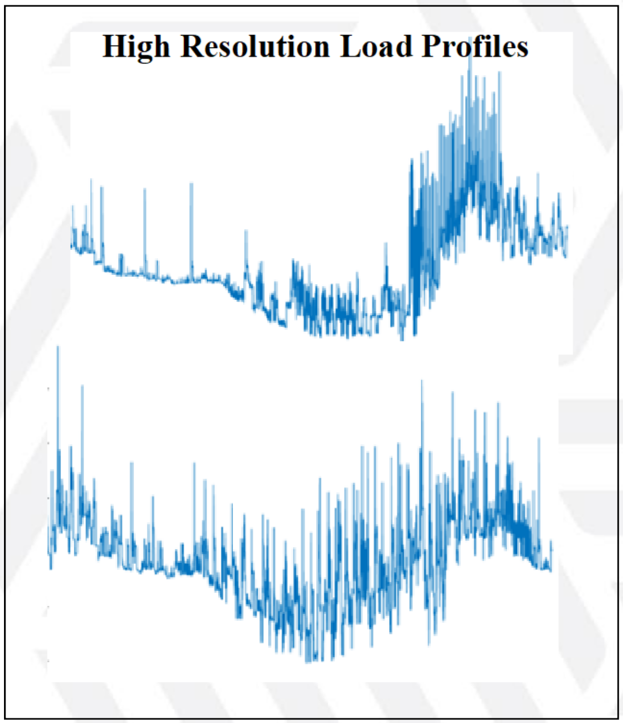


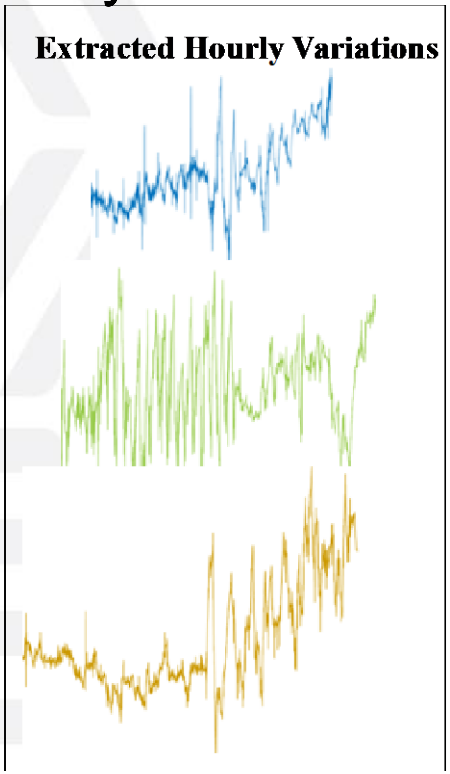




Variability Library

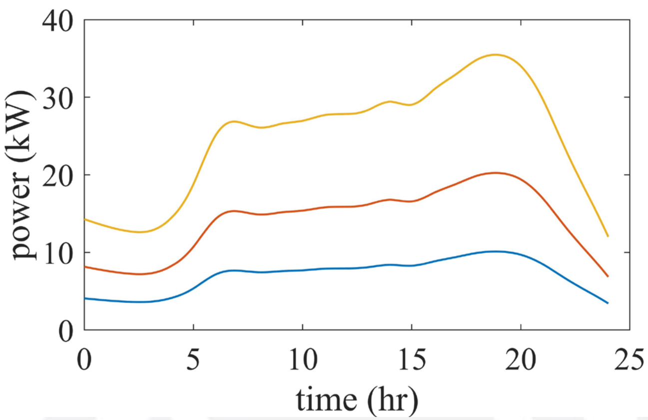
A discrete wavelet transform (DWT) based approach is used to build the variability library.



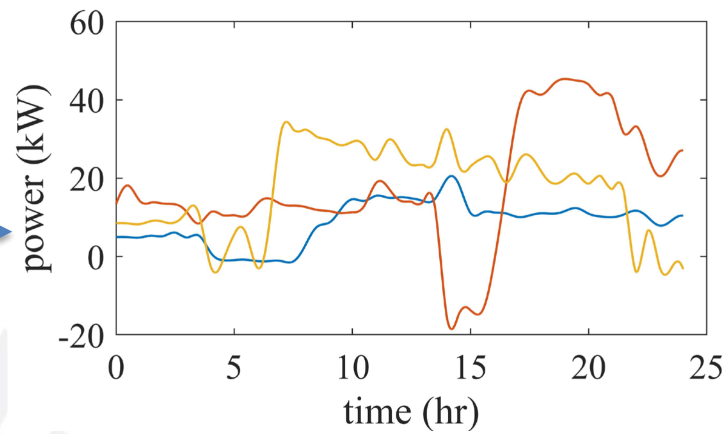


[9] Zhu, Xiangqi, and Barry A. Mather. DWT-Based Aggregated Load Modeling and Evaluation for Quasi-Static Time-Series Simulation on Distribution Feeders: Preprint. No. NREL/CP-5D00-70975. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2018

Synthetic Load Modeling

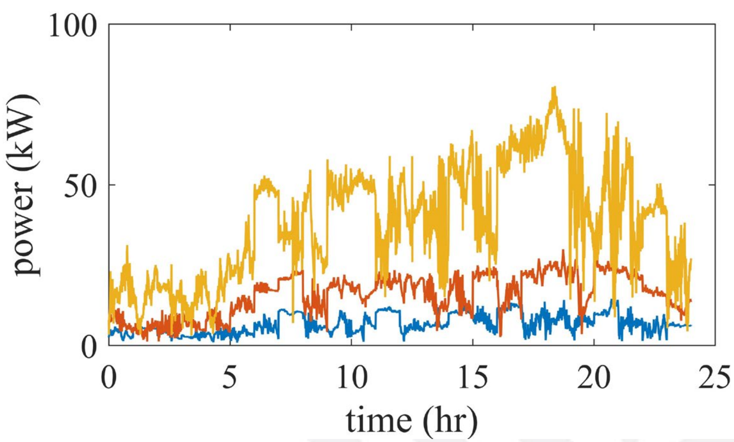


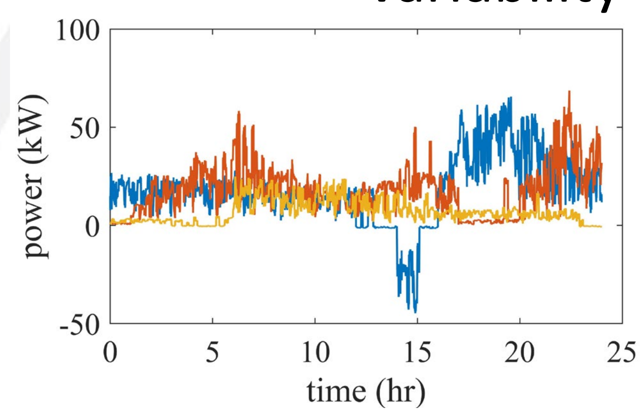
Add diversity only



Add variability only

Add both diversity and variability





Performance Test

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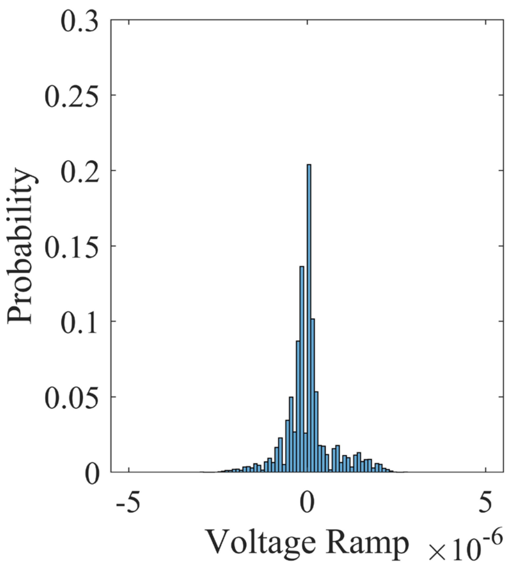
Regulator Move Comparison of Different Time Resolutions (IEEE 123-Bus Model)

	Regulator moves			
Resolution	1-second	1-minute	5-minute	30-minute
Loads with both diversity and variability	218	182	66	43
Plain Loads	31	31	31	29

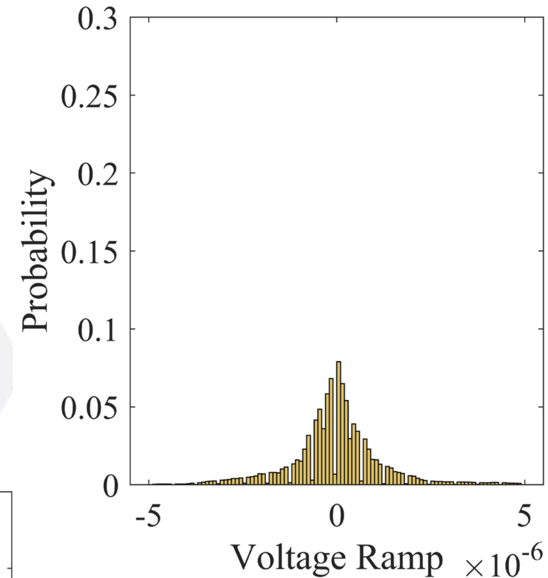
Regulator Move Comparison of Different Time Resolutions (Realistic Utility Feeder)

	Regulator moves			
Resolution	1-second	1-minute	5-minute	30-minute
Loads with both diversity and variability	78	14	8	4
Plain Loads	7	7	6	4

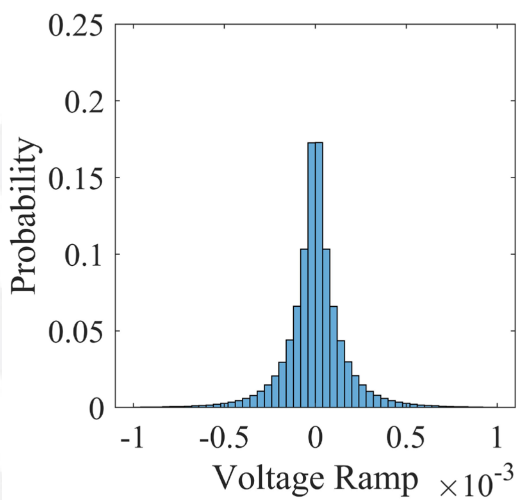
Performance Test



Plain loads



Diversity only



With both diversity and variability

Challenges to the Grid

- ► How to understand and host the increasing building loads
  - How to model the load for better analysis and planning
- ► How to manage and take advantage of the building loads
  - How to understand and estimate the load flexibility

Load Flexibility from Buildings

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- Residential and commercial buildings have great potential to provide demand response.

- To reveal the value of building loads providing demand response and incorporate the value into the distribution planning process, we need to:
  - Estimate demand-side management potential for buildings
  - Integrate in distribution planning the demand response capability from different building groups

One Cornerstone Solution:

- Behavior-based load models in conjunction with population characteristics from Census Data

Load Category

Modeled load

- Activity-based load:
  - Cooking, dishwashing, laundry, cleaning…
  - Predetermined appliance load profiles generated from American Time Use Survey data
- Temperature-based load:
  - HVAC, water heater
  - Equivalent thermal parameters model [9]
- Lighting loads:
  - Based on sunlight and activity

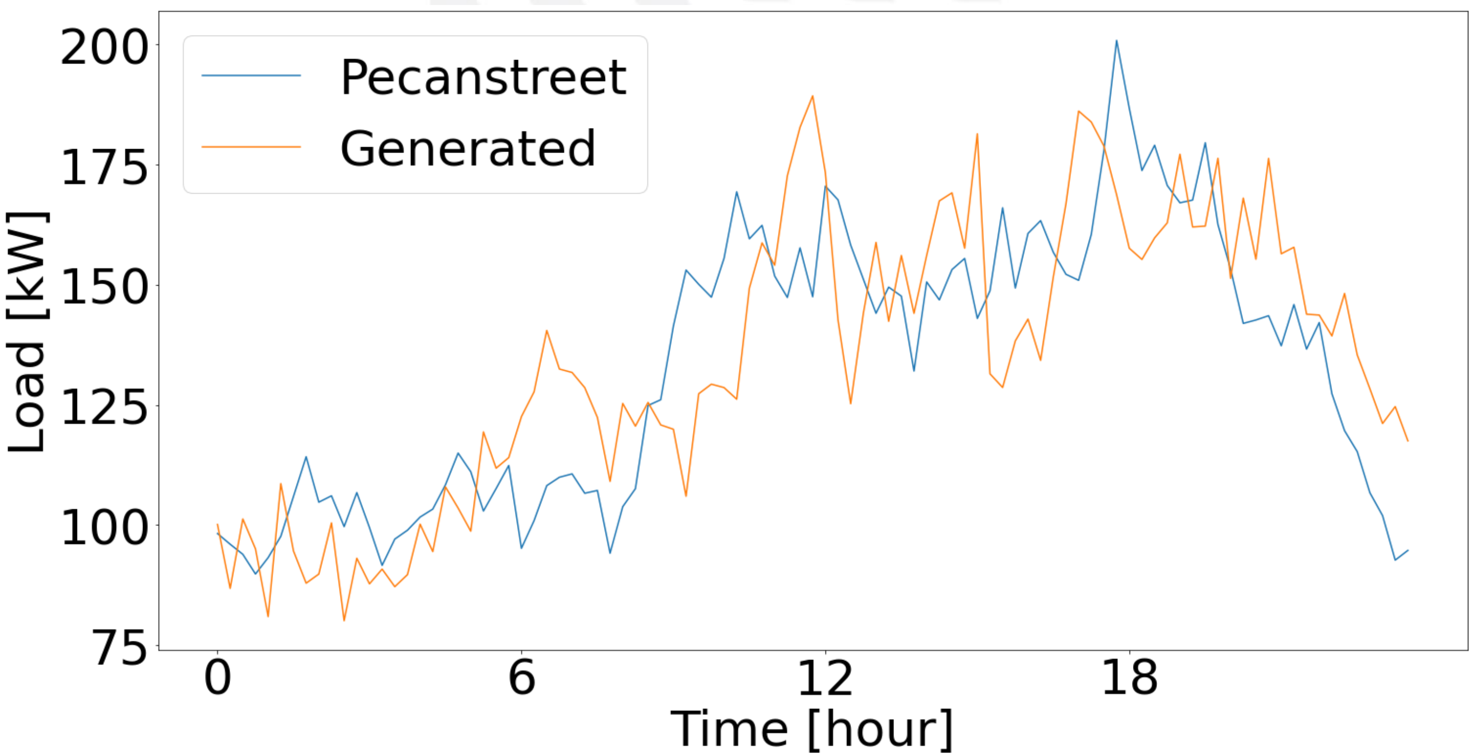
Load to be added:

- EV charging load

[9] Lu, Ning. "An evaluation of the HVAC load potential for providing load balancing service." *IEEE Transactions on Smart Grid* 3, no. 3 (2012): 1263-1270.

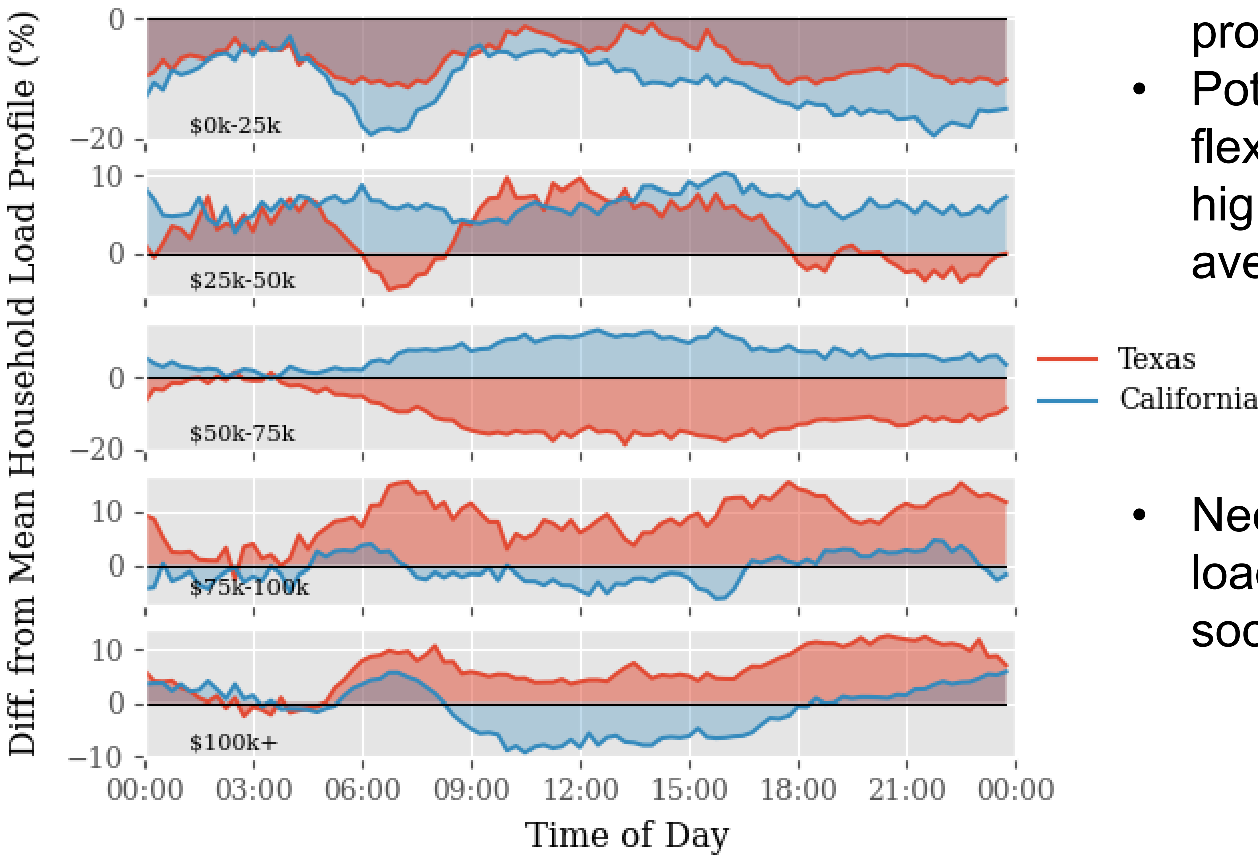
Load Modeling Validation

- Load profiles are generated for 100 houses in Texas
- Temperature and irradiance data in 2015
- Actual load profiles (2015) downloaded from Pecan Street website



Load Consumption Estimation Across Different Socioeconomic Groups

By Income



- Assume average load profile represents base load
- Potentially more load flexibility from groups with higher consumption than average

- Need to combine this with load analysis among other socioeconomic dimensions

[10] Isaac Bromley-Dulfano, Xiangqi Zhu, and Barry Mather, “Behavioral and Population Data-Driven Distribution System Load Modeling,” accepted by the 49th IEEE Photovoltaic Specialists Conference.

Load Flexibility in Distribution System Planning

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Accurate estimation of load flexibility can:

- Help utilities effectively plan and design demand response programs
- Help aggregators recruit appropriate buildings for different demand response programs
- Help utilities effectively plan infrastructure upgrades to avoid unnecessary costs

Questions public utility commissions can ask

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- How do you enable wide-access to charging facilities while maintaining high resilience and reliability of power distribution system?
- How to design incentive programs with varying charging prices which can enable managed charging without invasive control of human behavior?
- How to combine onsite generation solution with managed charging solution to achieve a cost-effective EV grid impact mitigation?
- What potential demand response capability can be provided from different groups of customers?

Resources for more information

- Zhu, Xiangqi, and Barry Mather. "Data-driven distribution system load modeling for quasi-static time-series simulation." *IEEE Transactions on Smart Grid* 11, no. 2 (2019): 1556-1565. https://ieeexplore.ieee.org/abstract/document/8827937

- Charging Infrastructure Technologies: Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE) https://www.energy.gov/sites/default/files/2021-06/elt202_bennett_2021_o_5-14_752pm_KS_TM.pdf

- Medium- and Heavy-Duty Electric Vehicle Charging https://www.nrel.gov/transportation/medium-heavy-duty-vehicle-charging.html

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